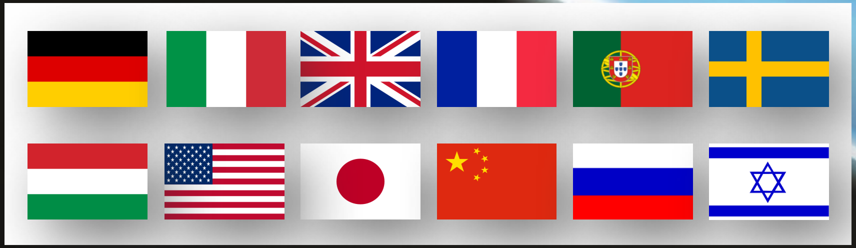
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

Horizon 2020 EuPRAXIA design study

Paul Andreas Walker (DESY)
On behalf of the EuPRAXIA collaboration team

8th International Particle Accelerator Conference
May 16th, 2017, Copenhagen, Denmark



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

European Plasma Research Accelerator with eXellence In Applications

Horizon 2020

- EuPRAXIA is a **conceptual design study** for a **5 GeV electron plasma accelerator** as an European research infrastructure

EuPRAXIA

UK
- University of Strathclyde
- STFC
- University of Manchester
- University of Liverpool
- Imperial College London
- University of Oxford

GERMANY
- DESY
- Universität Hamburg

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- Forschungszentrum Jülich

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- Wigner Fizikai Kutatóközpont

INTERNATIONAL
- CERN
- ELI Beamlines

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- LBNL
- UCLA

- EuPRAXIA is a **conceptual design study** for a **5 GeV electron plasma accelerator** as an European research infrastructure

- 125 scientists work in 38 international partners
  - 16 EU laboratories are beneficiaries
  - 22 associated partners contribute in-kind

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- EuPRAXIA is an EU Horizon 2020 project
  - One of two accelerator related design studies funded, other is EuroCirCol (FCC) from CERN

- Develop plasma technology for user readiness:
  - Incorporate established accelerator technology for optimal quality
  - Combine expertise from accelerator and laser labs, industry, and international partners

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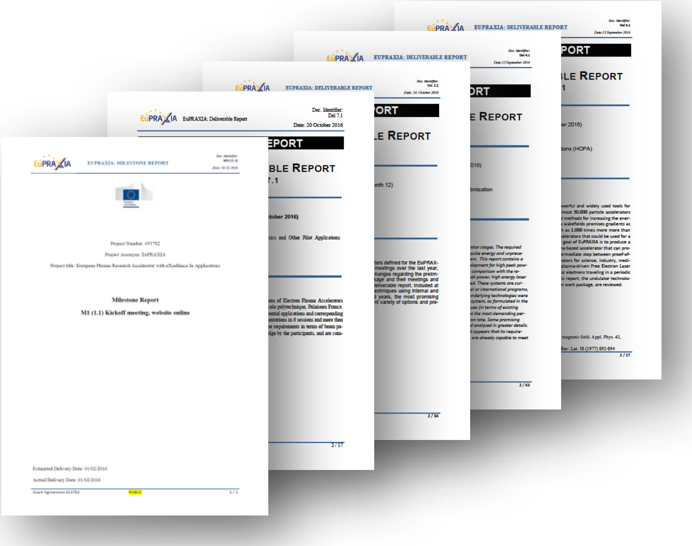
- 15 scientific reports produced in first 18 months



- Final **Conceptual Design Report** published in **October 2019**

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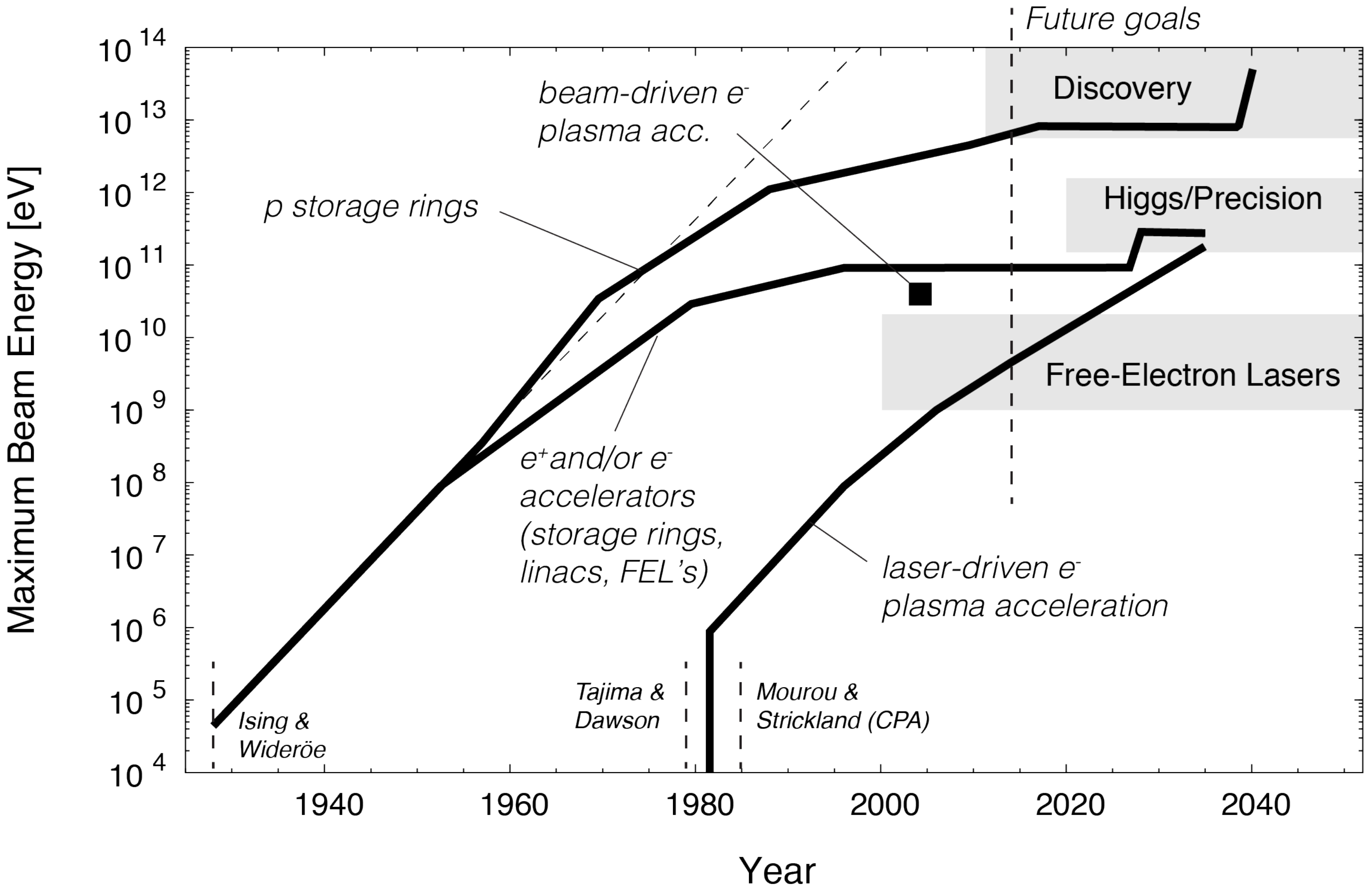
Livingston Curve

EuPRAXIA as stepping stone to users readiness



R. W. Assmann
F3iA, 12/2016

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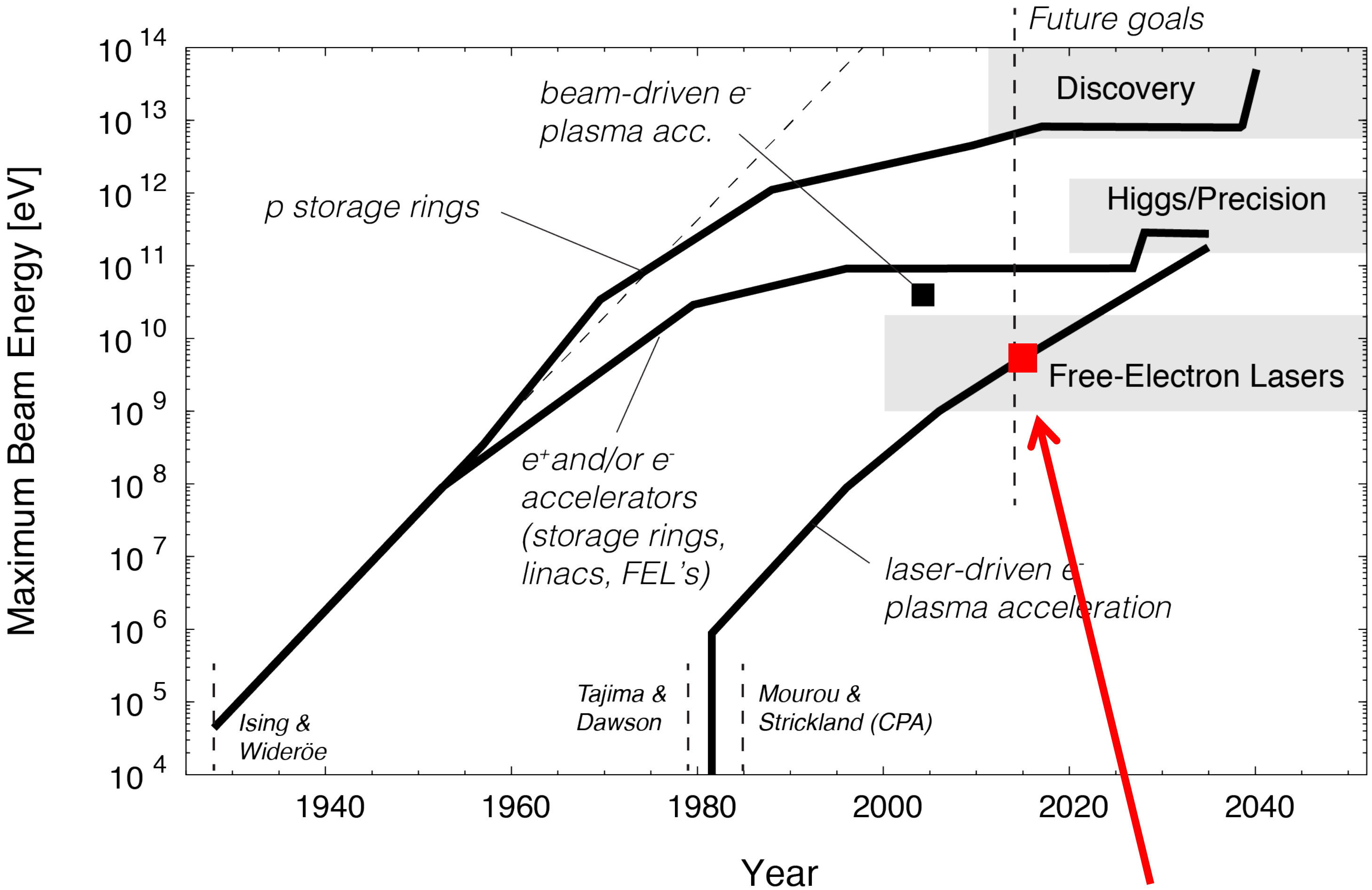

R. W. Assmann
F3iA, 12/2016

- Plasma accelerators reach energy regime of ongoing construction projects
- Acc. length of 9 cm instead of 100 m for multi GeV e^- beams [1]
- EuPRAXIA is **required stepping stone** to bring plasma accelerators to user readiness

[1] Leemans et al., Phys. Rev. Lett. 113, 245002 (2014)

Why use plasma accelerators?

- RF accelerators are an amazing success story: 30,000 accelerators are in use all over the world (started by R. Widerøe 90 years ago)
- Many further applications imaginable but some are constrained by practical concerns such as size and cost

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- Plasma accelerator techniques offer an innovative path to reduced size and cost with **applications** such as:
  - Ultra-compact **FEL's at universities**
  - Laser-driven electron beams as **medical imaging sources** in hospitals
  - Compact **electron irradiation**
  - **Portable industrial appl.** for X-ray inspections
  - HEP **table-top test** beams
  - Compact plasma HEP collider

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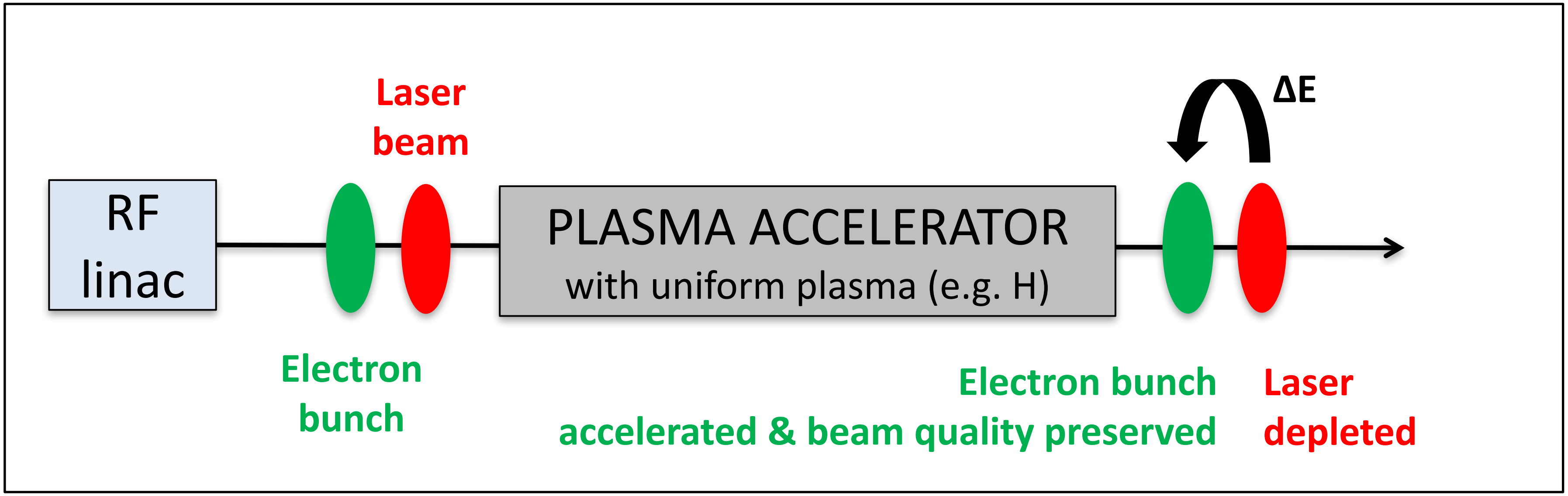
  - HEP **table-top test** beams
  - Compact plasma HEP collider
- "Compact/table-top" sources = **10's of meters rather than a kilometer** (fits on a trailer of a truck)

Plasma accelerator concepts: example one

- Plasma accelerators can be driven by lasers or electron beams
- EuPRAXIA studies 5 different approaches

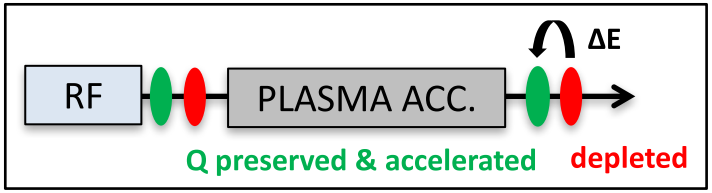
100 GV/m



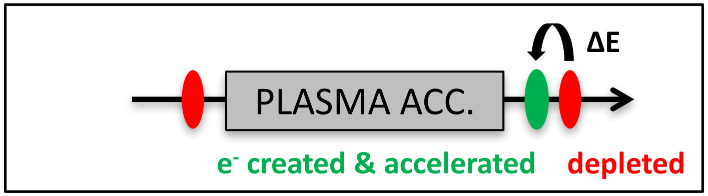
EuPRAXIA Plasma Accelerator Scheme

The 5 EuPRAXIA configurations

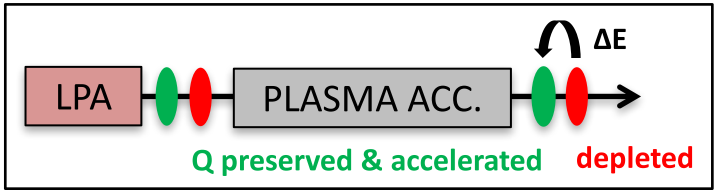
1) RF electron injector + laser plasma accelerator (LPA)
(LWFA with external injection from an RF accelerator)



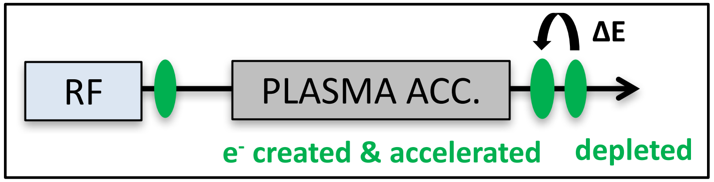
2) LPA with electron bunch created in plasma directly
(LWFA with internal injection)



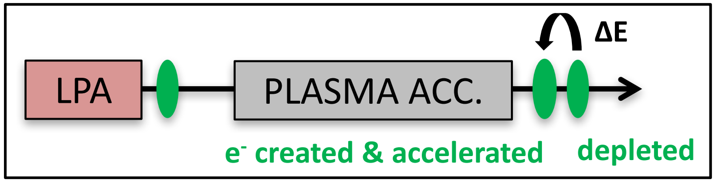
3) LPA electron injector + LPA
(LWFA with external injection from a LPA)



4) RF electron bunch as beam driver in LPA
(PWFA with an RF electron beam)



5) RF electron bunch as driver in a hybrid stage
(PWFA with LWFA produced electron beam or Trojan Horse scheme)



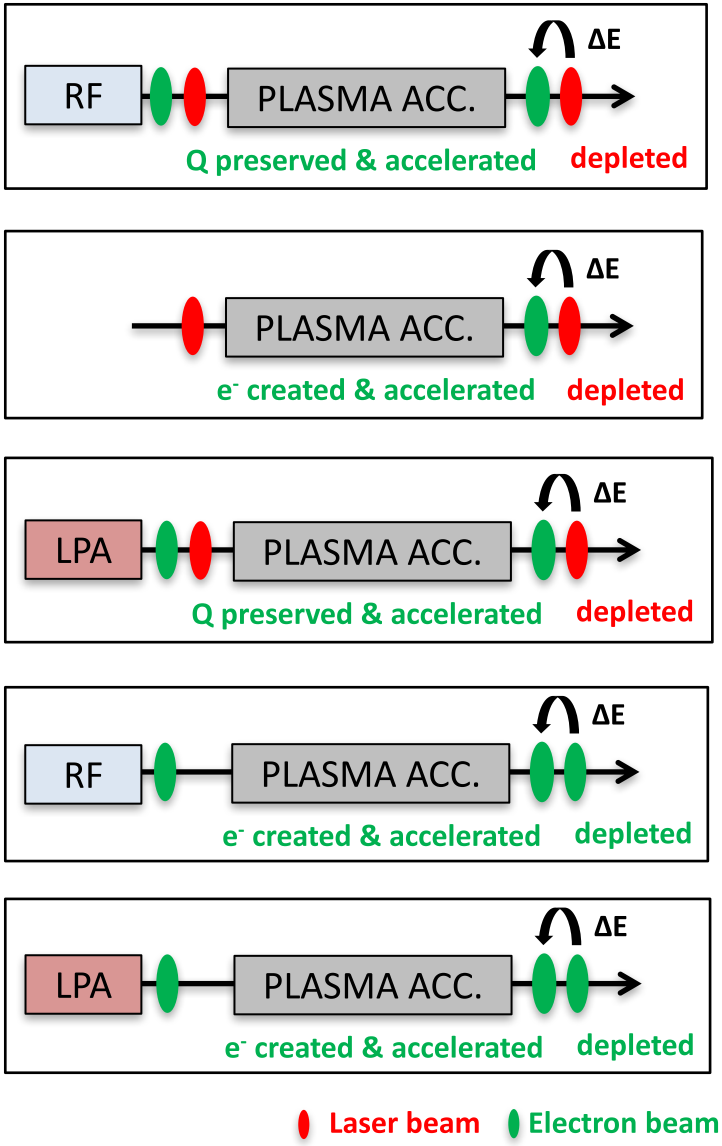
🟥 Laser beam 🟩 Electron beam

EuPRAXIA Plasma Accelerator Scheme

The 5 EuPRAXIA configurations

Horizon 2020

- Science & practical considerations will determine final choice of configuration(s)
- EuPRAXIA layout is being optimized for best synergy of lasers & RF technology



Target study parameter for electron and X-ray beams

- Electron and X-ray parameter in a nutshell:
  - 5 GeV electron beam
  - 1 – 0.1 nm FEL radiation

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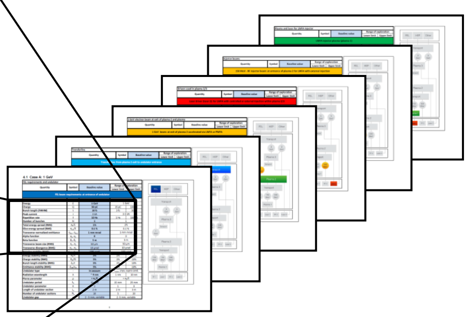
- Electron and X-ray parameter in a nutshell:
  - 5 GeV electron beam
  - 1 – 0.1 nm FEL radiation
- Detailed tables of electron and X-ray parameter exist

Quantity	Symbol	Baseline value	Range of exploration	
			Lower limit	Upper limit
Particle type	e-	Electrons	Electrons	
Energy	E	5 GeV	5 GeV	
Charge	Q	30 pC	15 pC	100 pC
Bunch length (FWHM)	τ	10 fs	3 fs	30 fs
Peak current	I	3 kA	3-5 kA	
Repetition rate	f	10 Hz	1 Hz	100 Hz
Number of bunches	N	1	1	
Total energy spread (RMS)	σ_E/E	1%	1 %	
Slice energy spread (RMS)	$\sigma_{E,s}/E$	0.1 %	0.1 %	
Transverse normalized emittance	$\varepsilon_{N,x}$, $\varepsilon_{N,y}$	1 mm mrad	1 mm mrad	



EuPRAXIA Deliverable Report 1.2 "Report defining preliminary study concept", 30. October 2016

- EuPRAXIA will be a low power accelerator aiming at high quality (later higher rep. rate)

EuPRAXIA simulations

- It is a design study:
  - Simulations and design work at the core of this project
  - Goal is start to end simulations, demonstrating required performance
- Various codes being used

PIC code used	Users
OSIRIS	IST, DESY
WARP	CNRS/LPGP, CEA
CALDER-Circ	LOA
SMILEI	CNRS/LLR
ALaDyn, Architect	INFN_SparcLab (PISA_ILIL)
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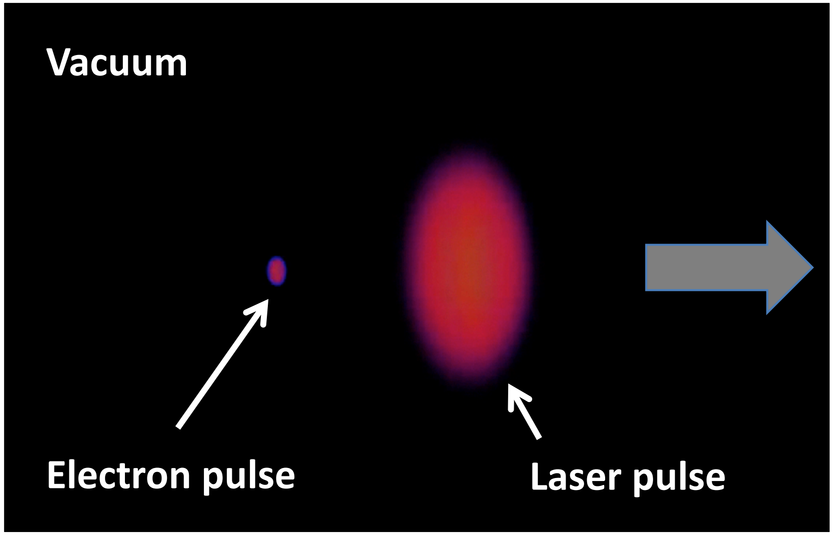
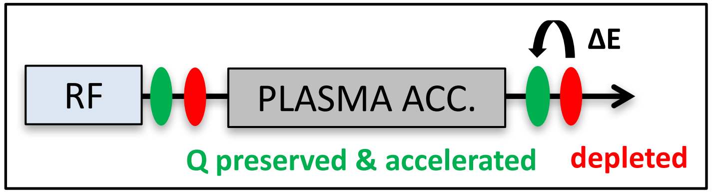


Á. Ferran Pousa, R. Assmann, A. Martinez de la Ossa. IPAC17 paper ***TUPIK007****.*



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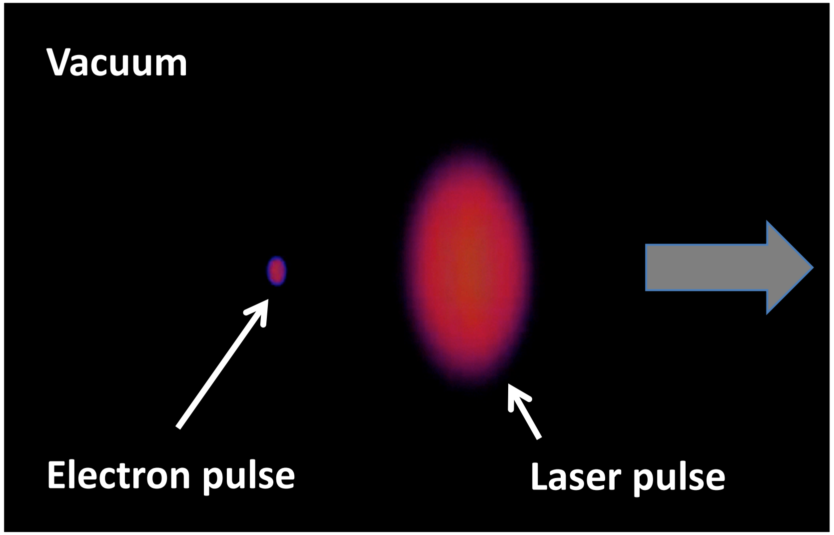

Initial electron beam:
E = **100 MeV**,
Relative energy spread = **0.1 %**
Norm. trans. emittance = **1 mm mrad**
Q = 1 pC, τ = 3.3 fs (rms), σ_x = 1.3 µm

Laser pulse:
a_0 = 3.1, λ = 800 nm, I_{FWHM} = 100 fs,
w_0 = 54 µ m, E = 100 J, 1 PW peak power

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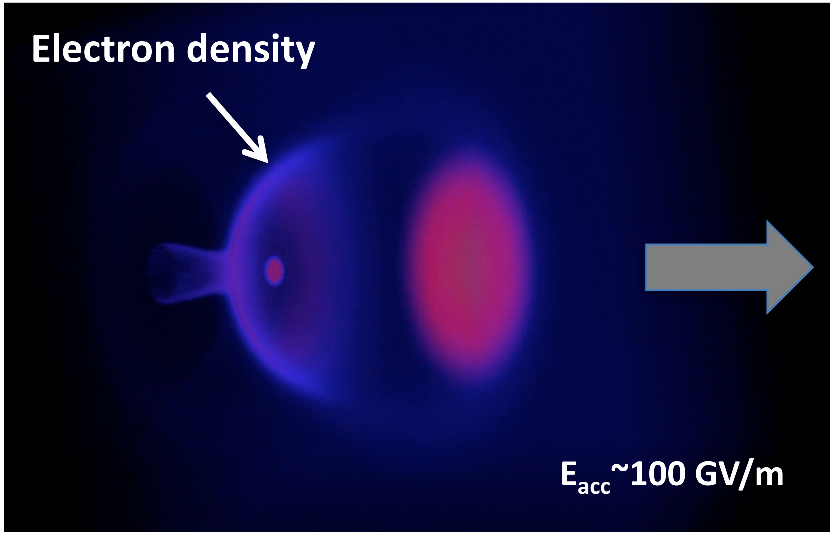

The acceleration regime:
close to blowout
2D simulation: the 3D animation was made assuming cylindrical symmetry

Plasma:
Density = 1.2×10^{17} cm^{-3}
Length = **2.5 cm**

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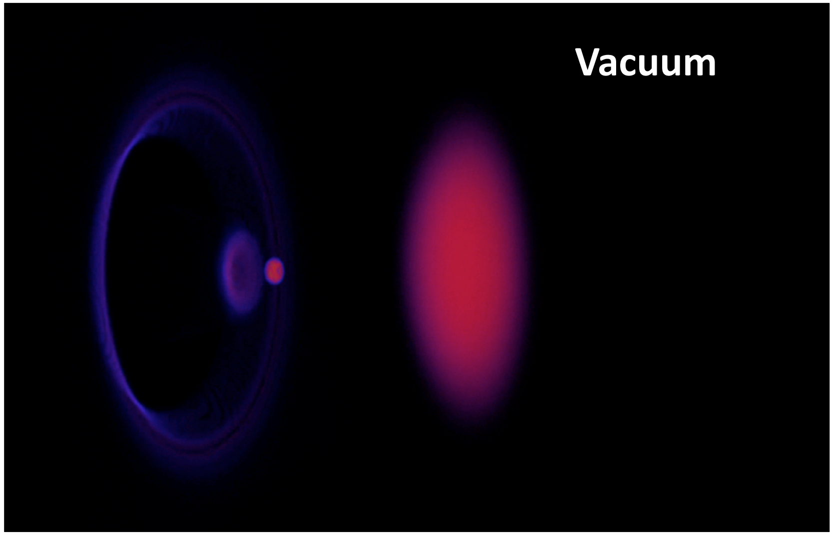
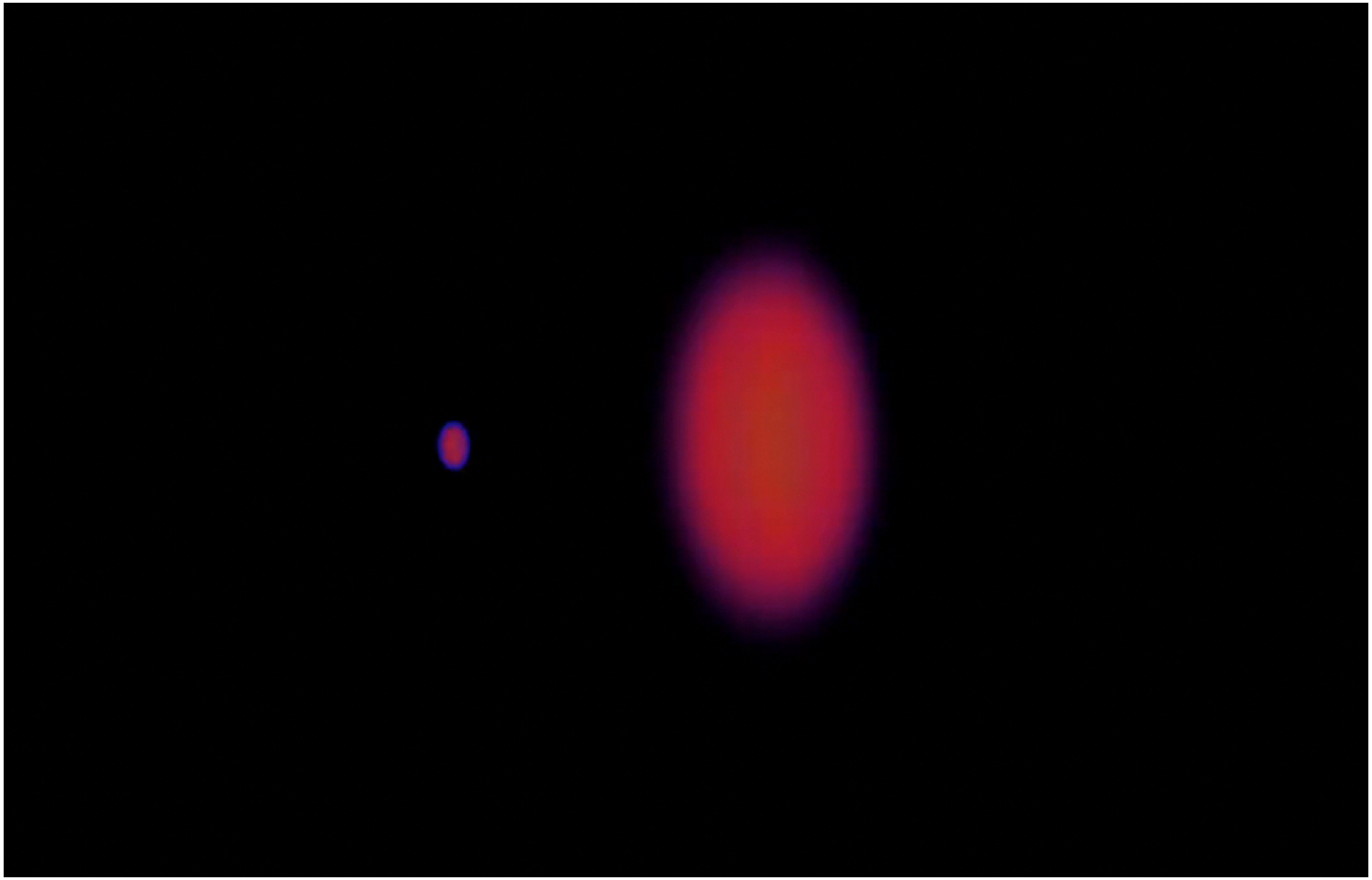


Electron beam after plasma:
Energy = **1 GeV** (initial 100 MeV)
Relative energy spread **= 1.5%** (initial 0.1 %)
Normalized emittance = **0.995 µrad m**
(initial 0.99 µrad m)

Á. Ferran Pousa, R. Assmann, A. Martinez de la Ossa. IPAC17 paper ***TUPIK007****.*

EuPRAXIA simulations

One example



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EuPRAXIA simulations

Imperfections of laser and plasma

- Of particular importance is the sensitivity to **initial fluctuations**
  - plasma density
  - alignment
  - particle beams
  - laser pulses

- Use of **realistic profiles**
  - Simulation work package is identifying the role of non-standard laser profiles such as non pure Gaussean beams:

$$I(\rho) = I_0 \exp\left[-(\rho / w)^{\alpha}\right]$$

I = laser intensity, $\boldsymbol{\rho}$ = distance ,
w = transverse size , $\alpha = 2$ (Gaussian),
$\alpha > 2$ (“top-hat”)

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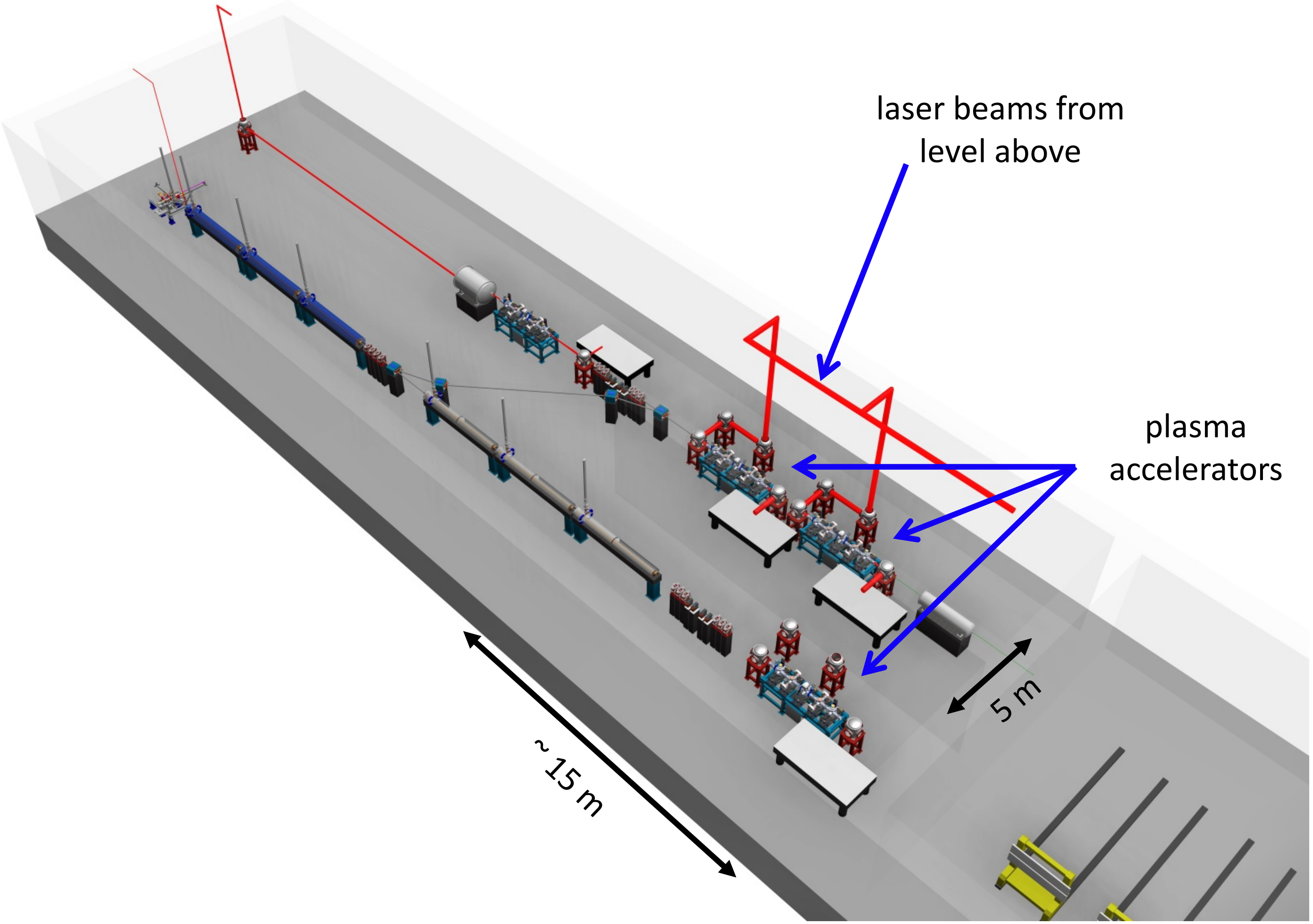
Layout proposal
combining all configurations



3D design by Dariusz Kocoń (ELI-Beams)

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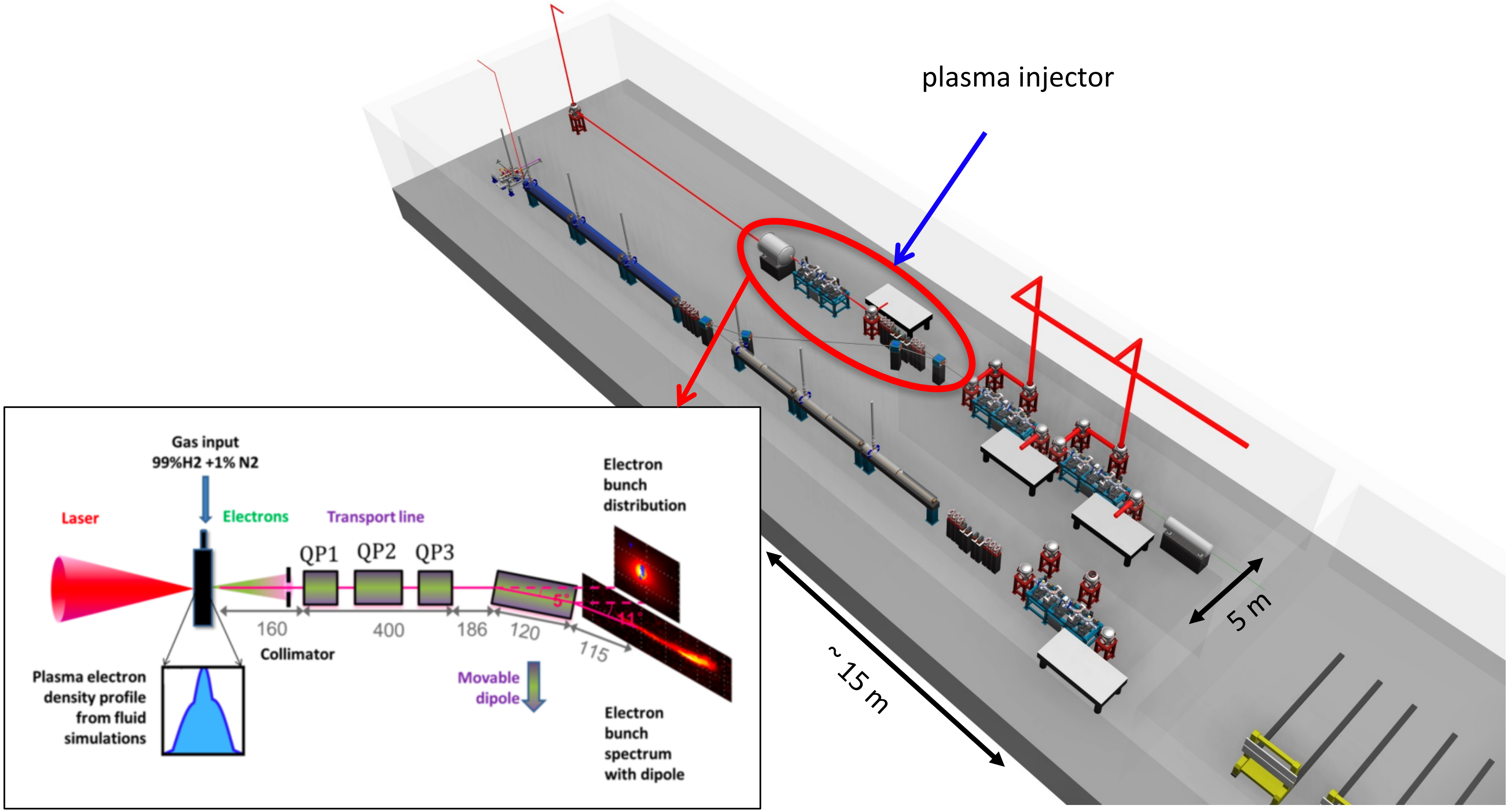

See poster: B. Cros et al., 'Electron injector for multi-stage laser-driven plasma accelerators', IPAC'17, **WEPVA001**

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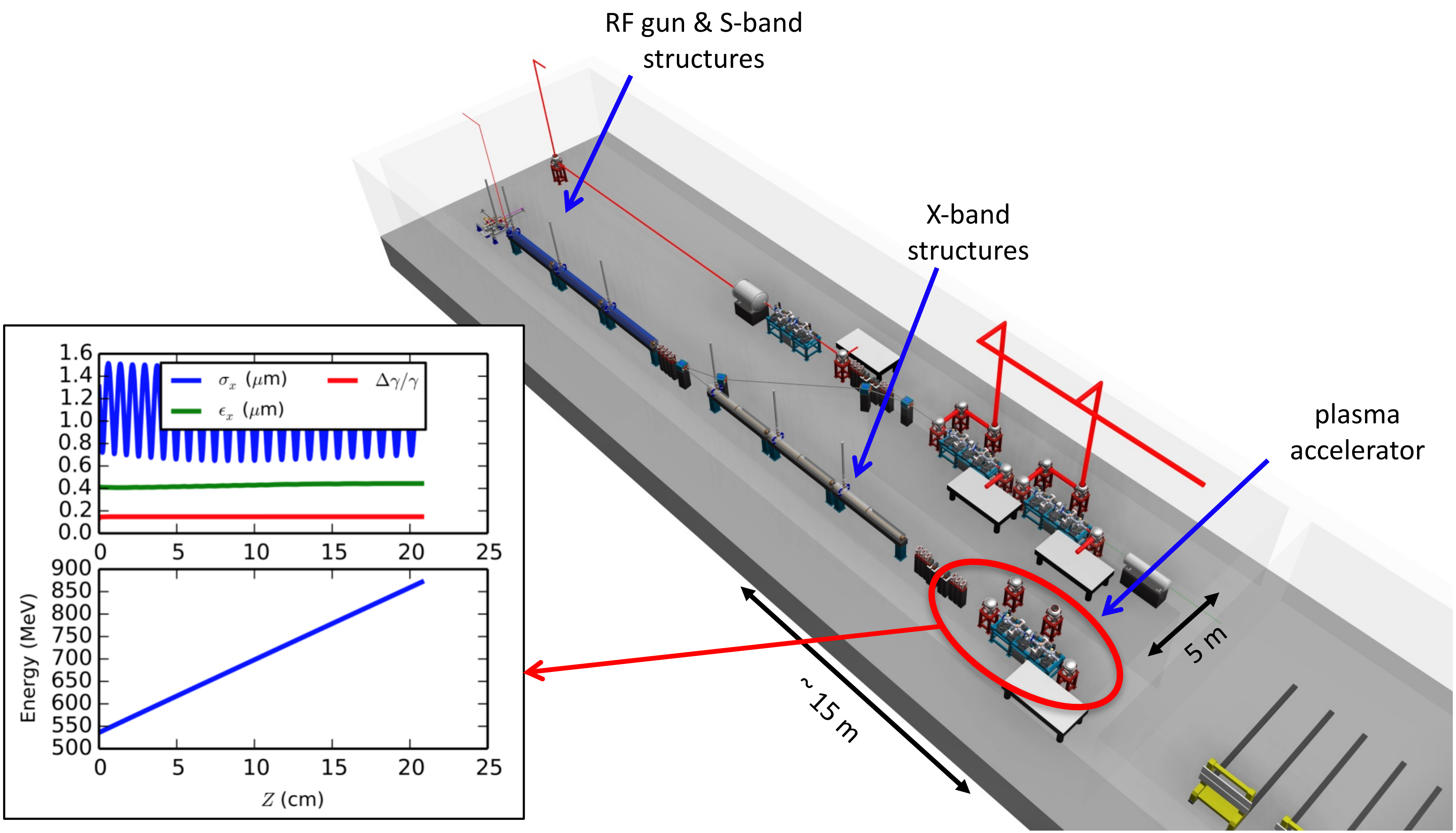

RF gun & S-band structures

X-band structures

plasma accelerator

A. Marocchino et al., simulations with hybrid code Architect, Nucl. Instr. Meth. Phys. Res. vol. 829, 2016.

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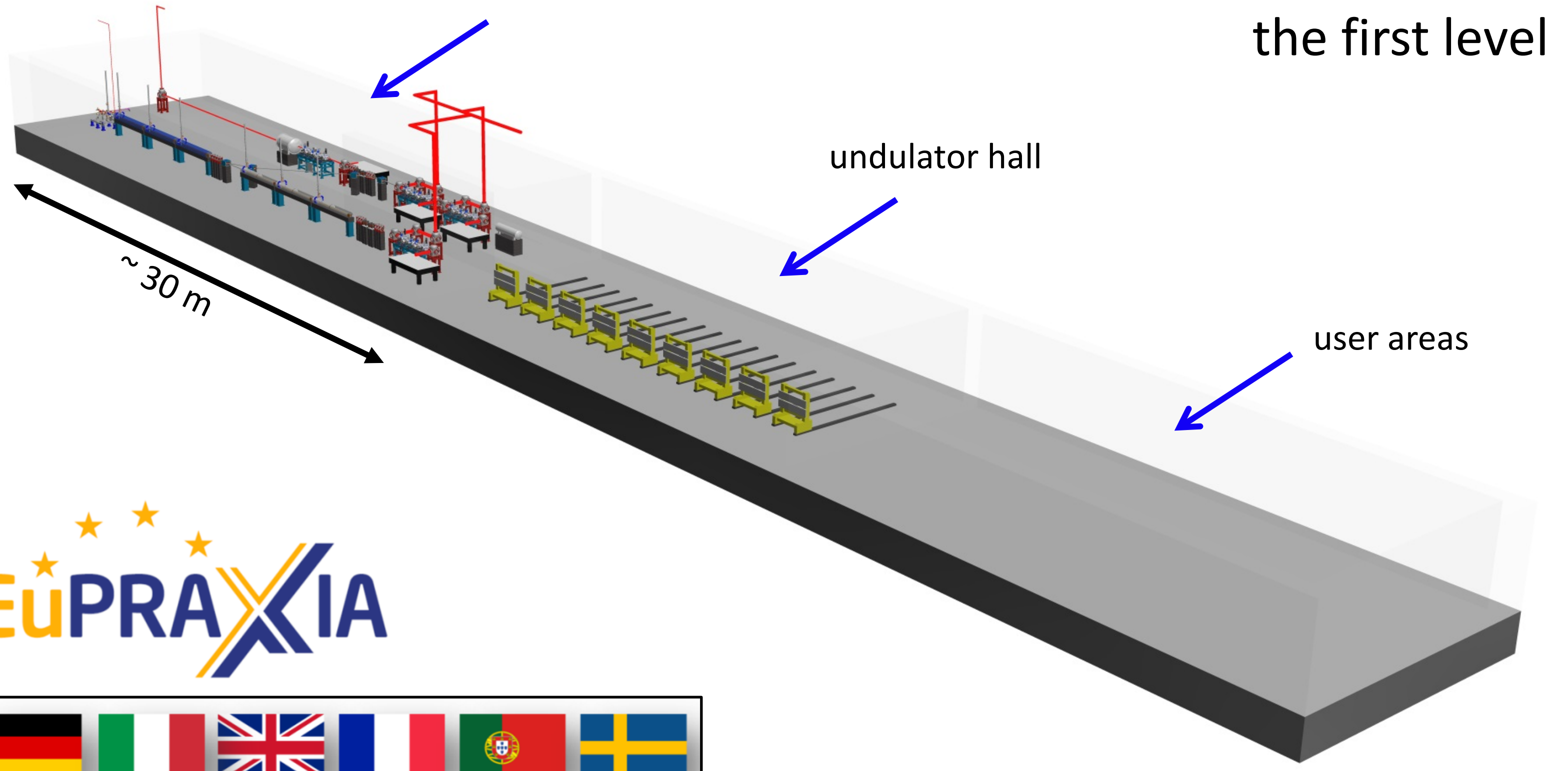
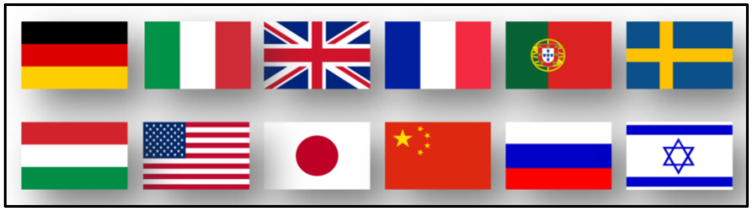
Layout proposal

Accelerator research, undulators and user areas are located on the first level

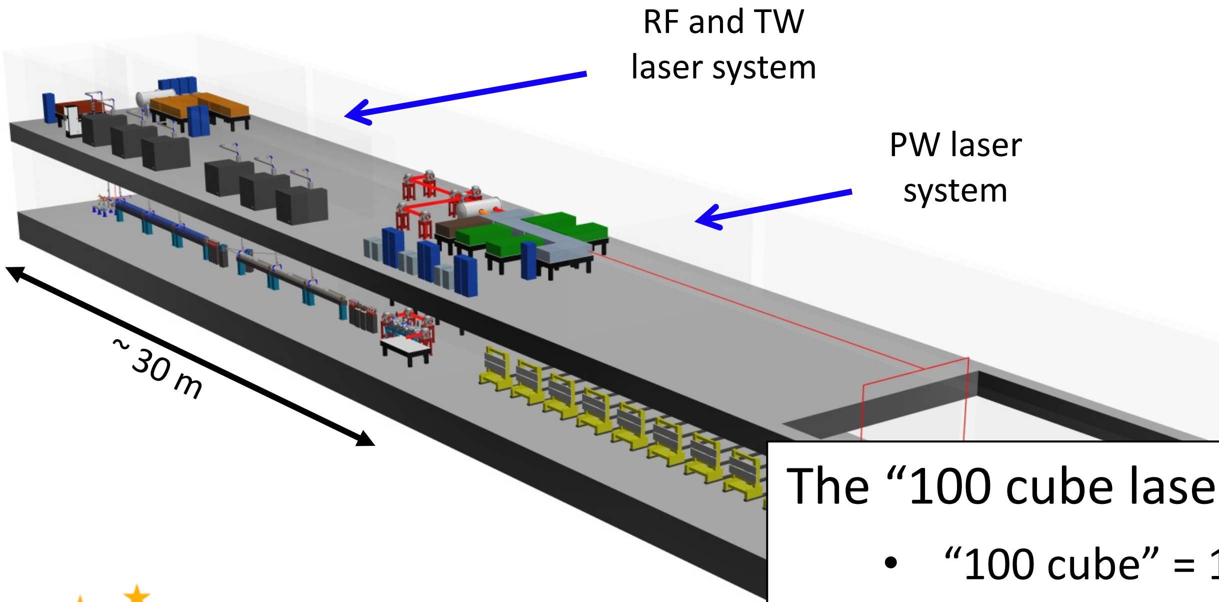




See poster: P.A.Walker et al., ‘Layout and space considerations for EuPRAXIA’, IPAC’17, **TUPIK012**

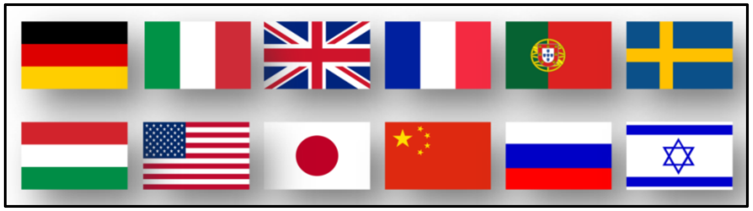
Layout proposal

RF and laser infrastructure on second level



THALES
proton laser
Cilex Apollon
Amplitude
STFC Central Laser Facility
1st Laser design and optimization workshop
EuPRAXIA

EuPRAXIA



The "100 cube laser challenge":

- "100 cube" = 100 J, 100 fs, 100 Hz
  => 1PW @ 100Hz
- Not a complete Ti:Sa laser system
- Diode-pumped solid-state laser scheme
- 2nd laser system (Ti:Sa) operates at lower energy and shorter pulse length

Is EuPRAXIA Accelerator Really Compact?

- Detailed estimates of required space are ongoing:
  - Acc. tunnel **+** infrastructure **about 300 – 600 m^2 for 5 GeV** (depending on conf.)
  - Potential **factor of 5-10 footprint reduction** compared to RF based electron linac
  - Reduced footprint has potential to open many additional applications

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- **Sufficient beam quality** required which is **central goal of EuPRAXIA**
  - Improve energy spread (“beam loading” [3] or “modulated plasma density” [4])
- EuPRAXIA will initially be **low power and low wall-plug power efficiency**
  - Efforts with industry and laser institutes to improve rep. rate & efficiency of currently used laser systems (also incorporate fiber-based lasers with 30 % eff.)

[3] S. Van der Meer, CLIC Note No. 3, CERN; PS, ‘85-65
[4] R. Brinkmann et al., arXiv:1603.08489, accepted for publication in PRL

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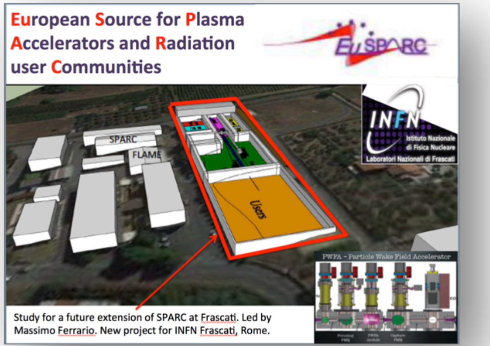
  - Improve energy spread (“beam loading” [3] or “modulated plasma density” [4])
- EuPRAXIA will initially be **low power and low wall-plug power efficiency**
  - Efforts with industry and laser institutes to improve rep. rate & efficiency of currently used laser systems (also incorporate fiber-based lasers with 30 % eff.)

- EuPRAXIA report will be technical design report and project proposal:
  - Performance, required tolerances, footprint and cost will be assessed
  - We **hope for significant cost benefit** from this new technology

[3] S. Van der Meer, CLIC Note No. 3, CERN; PS, ‘85-65
[4] R. Brinkmann et al., arXiv:1603.08489, accepted for publication in PRL

Site study

- EuPRAXIA design study is site independent
- Five possible sites have been discussed so far
- We invite the suggestions of additional sites

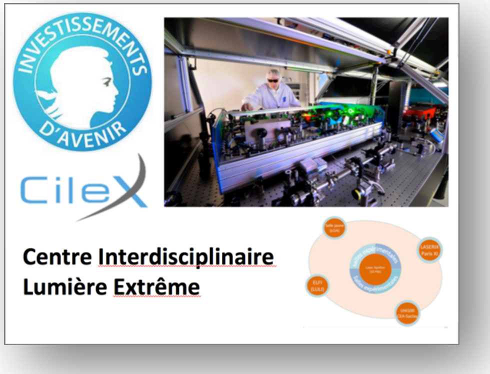

European Source for Plasma Accelerators and Radiation user Communities

Study for a future extension of SPARC at Frascati. Led by Massimo Ferrario. New project for INFN Frascati, Rome.


SINBAD

Facility for Short INnovative Bunches and Accelerators at DESY (ex DORIS collider)

- dedicated acc. R&D facility
- 280 m beam tunnel
- accelerator science programs
- adjacent laser laboratories
- photon science labs
- central campus location
- home for future ATHENA, facility, if funded by Helmholtz



Centre Interdisciplinaire Lumière Extrême

Eli Beamlines
Prague, Czech Republic

Central Facility
Didcot, UnLaser ited Kingdom

Is EuPRAXIA Really Compact?

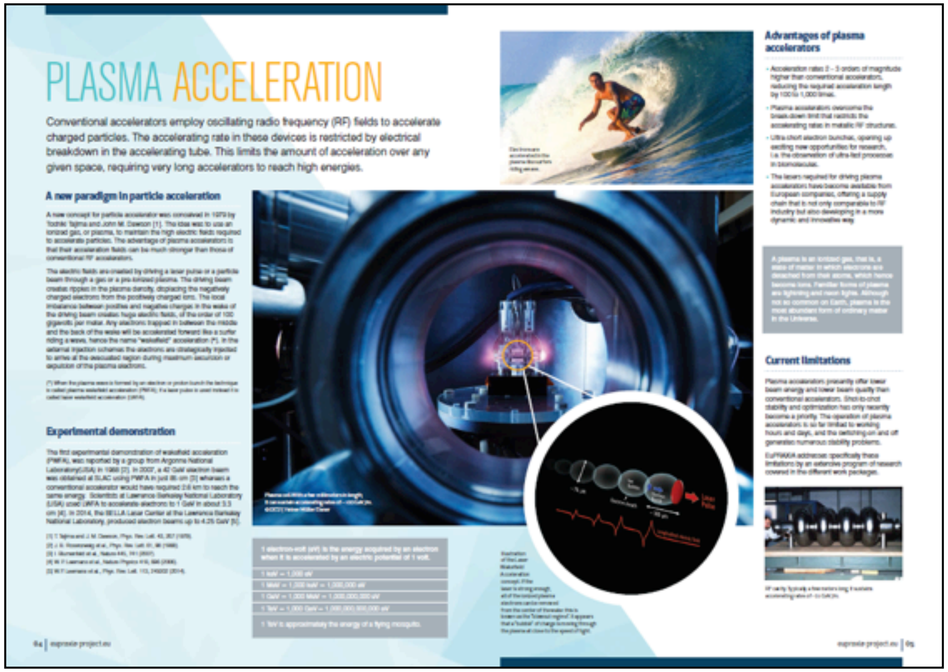
Rigshospitalet Copenhagen

Is EuPRAXIA Really Compact?


Rigshospitalet
Copenhagen

Dissemination

See booth number 20 from The University of Liverpool for more information on EuPRAXIA.



PLASMA ACCELERATION

Conventional accelerators employ oscillating radio frequency (RF) fields to accelerate charged particles. The accelerating rate in these devices is restricted by electrical breakdown in the accelerating tube. This limits the amount of acceleration over any given space, requiring very long accelerators to reach high energies.

A new paradigm in particle acceleration

Experimental demonstration

Advantages of plasma accelerators

Current limitations

EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

DESIGNING THE FUTURE

The EuPRAXIA Consortium is preparing a conceptual design for the world's first multi-GeV plasma-based accelerator with industrial beam quality and dedicated user areas.

ADVANCED TECHNOLOGIES

EuPRAXIA joins novel acceleration schemes with modern lasers, the latest correction technologies and large-scale user areas. The consortium offers unique training opportunities for researchers in a multidisciplinary field.

OPENING NEW HORIZONS

The project will bridge the gap between successful proof-of- principle experiments and ground-breaking, ultra-compact accelerators.

With a smaller size and improved efficiency, plasma-based technologies have the potential to revolutionize the world of particle accelerators multiplying their applications to medicine, industry and fundamental science.

INTERNATIONAL COLLABORATION

EuPRAXIA brings together a consortium of 16 laboratories and universities from 5 EU member states. The project, coordinated by DESY, is funded by the EU's Horizon 2020 programme.

The consortium holds open international events to strengthen collaborations, to connect to interested users from FEL's, high-energy physics, medicine and industry, and to assess the development of the project.

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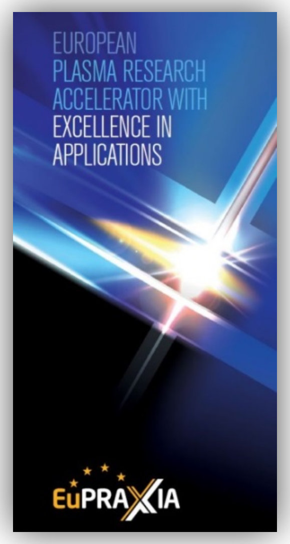

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THE EuPRAXIA FILES

ISSUE 1 – May 2016

Foreword

Novel accelerators have seen strong advances not only in achievable beam energy but also in beam quality. This success story is still developing, as you can see from the publications that we collect in this first edition of "The EuPRAXIA Files". As many of you are aware, the Horizon2020 Design Study EuPRAXIA aims at a conceptual design for a European plasma accelerator with usable beams. Instead of another newsletter we will regularly provide you with summaries of recent publications, letting the science speak for itself. EuPRAXIA has meanwhile had an excellent project start and is gearing up to a workshop in Pisa at the end of June, organized together with the European Network for Novel Accelerators EuroNNAc2 and EuCARD2. For further news on EuPRAXIA please visit our website or read regular updates in "Accelerating news". We wish you some inspirational science readings in this edition of "The EuPRAXIA Files", prepared by the EuPRAXIA outreach team in Liverpool with Ricardo Torres as lead editor.

Research Highlights

Berkeley Lab Scientists Create the First-ever, 2-stage Laser-plasma Accelerator Powered by Independent Laser Pulses

Researchers from the Lawrence Berkeley National Laboratory in the US have made an important breakthrough in the development of ultra-compact high-energy plasma-based accelerators.

In a paper recently published in Nature, they demonstrate for the first time the technique of staging, or sequencing multiple plasma accelerators independently powered. Staging is critical for high-energy physics applications of laser-plasma accelerators, as it enables to achieve higher beam energies, while maintaining accelerating gradients orders of magnitude above conventional technology.

In these experiments, electrons from one laser-plasma accelerator were transported into a second laser-plasma accelerator, powered by a second laser pulse, and accelerated. What was particularly novel about this experiment is that a plasma-based lens was employed to transport the beam between stages and a plasma mirror was used to couple in the second laser pulse. These plasma-based components allowed the system to remain extremely compact.

Members of the BELLA Center staging experiment team, from left, are Eric Esarey, Wim Leemans, Jeroen van Tilborg, Carlo Benedetti, Kelly Swanson, Anthony Gonsalves, Joost Daniels, Sven Steinke, and Kei Nakamura. Not pictured are Cameron Geddes, Carl Schroeder, Nicholas Matlis, and Brian Shaw. (Photo credit: Roy Kaltschmidt/Berkeley Lab)

With this result, one can envision scaling to beam energies of interest for high-energy physics applications in a compact footprint. However, these results are a first step toward that vision—experiments at higher beam energy, with higher efficiency and improved beam quality, will need to be performed to further develop plasma-based technology for next-generation colliders.

Read more at: http://newscenter.lbl.gov/2016/02/01/2-stage-laser-plasma-accelerator/

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www.eupraxia-project.eu

#EuPRAXIA
#plasma
#accelerator

Conclusion

- EuPRAXIA is preparing **conceptual design for a European research facility** with applications in science, industry & medicine.
- Provide a **5 GeV electron beam** based on a laser and/or a beam driven **plasma acceleration** approach.
- Design will include user areas for **FEL radiation**, “table-top” **test beam for HEP detectors tests**, and **compact X-ray source** for medical imaging.

Conclusion

- EuPRAXIA is preparing **conceptual design for a European research facility** with applications in science, industry & medicine.
- Provide a **5 GeV electron beam** based on a laser and/or a beam driven **plasma acceleration** approach.
- Design will include user areas for **FEL radiation**, “table-top” **test beam for HEP detectors tests**, and **compact X-ray source** for medical imaging.
- This is a Horizon 2020 project and we acknowledged the essential support from the EU.
- Please visit posters for more details:
  - Á. Ferran Pousa, “Visualization code”, **TUPIK007**
  - P. A. Walker, “EuPAXIA Layout”, **TUPIK012**
  - F. Filippi et al., “Gas-filled capillaries” **TUPIK023**
  - B. Cros et al., ”Electron injector”, **WEPVA001**

Thank you for your attention

Horizon 2020

The EuPRAXIA team

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3rd European Advanced Accelerator Concepts workshop

Supported by EU/ARIES via EuroNNAc3
24-30 September 2017, La Biodola - Isola d'Elba – Italy

Laser technology for advanced accelerators
Dielectric structures and other novel technologies
Advanced and novel accelerators for High Energy Physics
High gradient and multibunch acceleration in metallic structures
(C-X-band and beyond) with innovative power generation schemes
Plasma accelerators driven by: modern lasers, electron beams, proton beams
Computations for Accelerator Physics Advanced beam diagnostics for beams and plasma
Novel schemes using advanced technologies (table-top FEL, medical imaging ...)

EAAC 2017

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